Recent Experience with the CQE™

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Increasing public awareness about the health of the global environment, tightening emissions regulations, growing competition among power producers, and advances in power generation technology are transforming the business of power generation worldwide. This transformation has further complicated fuel purchase decisions that profoundly affect the cost of electricity.

CQE (the Coal Quality Expert) is a software tool that brings a new level of sophistication to fuel decisions by seamlessly integrating the system-wide effects of fuel purchase decisions on power plant performance, emissions, and power generation costs.

The result of a $21.7 million U.S. Clean Coal Technology project sponsored by the Department of Energy and the Electric Power Research Institute, CQE offers unparalleled advancements in technical capability, flexibility, and integration.

The CQE technology, which addresses fuel quality from the coal mine to the busbar and the stack, is an integration and improvement of predecessor software tools including:

- EPRI's Coal Quality Information System
- EPRI's Coal Cleaning Cost Model
- EPRI's Coal Quality Impact Model
- EPRI and DOE models to predict slagging and fouling

CQE can be used as a stand-alone workstation or as a network application for utilities, coal producers, and equipment manufacturers to perform detailed analyses of the impacts of coal quality, capital improvements, operational changes, and/or environmental compliance alternatives on power plant emissions, performance and production costs. It can be used as a comprehensive, precise and organized methodology for systematically evaluating all such impacts or it may be used in pieces with some default data to perform more strategic or comparative studies.

Overview of the Project

The CQE project was conceived by EPRI to integrate the results and products of several on-going R&D projects into computer software that would become a worldwide standard for addressing fuel-related issues in the power industry. EPRI and DOE sponsored numerous coal quality R&D projects in the late 1970s and early 1980s to carefully examine and document the answers to questions that need to be addressed before a utility can be certain that it is operating its power plants within emissions limitations at the lowest possible cost:

- What are the economics of burning a prospective coal?
- How would the delivered price of coal change if the supplier cleans or blends the coal(s) to produce a product with quality characteristics different than the coal currently delivered to the power station?
- To what degree can the quality of the coal currently delivered to the power station be changed?
- What power plant equipment and systems are most affected or limited by coal quality?
- What are the trade-offs between increased capital spending at the power stations and increased cost of fuel for higher quality?
- How will alternative emissions control strategies affect the production cost of electricity at a specific unit?
- Are the slagging and fouling consequences of burning a prospective coal affordable?

Coal producers and equipment manufacturers must also address these questions from a different perspective to assess the potential value of alternative products and services for utilities. For example, a coal producer contemplating changes to an existing cleaning plant or a manufacturer trying to sell replacement parts for coal pulverizers would both be interested in using a model that could accurately determine pulverizer performance, power consumption and maintenance costs for potential utility customers to provide a fuel that matched plant/unit capabilities and goals. CQE was conceived as the tool to serve the needs of these prospective users as well as the utilities that were already using CQIM and related EPRI and DOE software.

Background and History of the Project

In the mid 1970s, EPRI initiated its effort to understand the linkage between coal quality and power plant performance, emissions, and economics. Initial studies focused on the potential savings in capital cost of new coal-fired power stations that would result from the use of cleaner coal (1). To quantify the costs of producing cleaner coals and to evaluate the potential for physical coal cleaning to improve the quality of U.S. coals for power generation, EPRI initiated a coal cleanability characterization program at the Coal Cleaning Test Facility (CCTF) which it constructed in 1980-81. The facility's mission also included the demonstration of emerging coal cleaning technologies to accelerate their commercial deployment.

In 1982 EPRI started a parallel effort to build a state-of-the-art computer model that would predict power plant performance, production costs, and emissions based on laboratory and bench-scale coal quality measurements. The initial effort was focused on defining the specifications for the model and assembling the proven methodologies for predicting coal quality impacts on various power plant systems and components. A complementary effort to perform laboratory, bench-scale, and pilot-scale coal quality analyses was also initiated by EPRI in the mid 1980s, and since the Coal Cleaning Test Facility became the source for most of the combustion test samples, its name was changed to the Coal Quality Development Center (CQDC).

When the DOE Program Opportunity Notice for the Clean Coal Technology Program was issued on February 17, 1986, Combustion Engineering Inc. on behalf of EPRI prepared a proposal for the development of the Coal Quality Advisor that was later renamed the Coal Quality Expert, or CQE. The project proposed by Combustion Engineering included coal cleanability characterization of selected additional U.S. coals, laboratory, bench-scale, and pilot-scale combustion testing of representative samples of the run-of-mine and clean coal; full-scale power plant testing of those coals to verify coal quality effects; and the development of the software tool that would replace pilot-scale and full-scale demonstrations in the future. The proposal by Combustion Engineering was not selected from the initial awards for Round 1 of the Clean Coal Technology Program, so EPRI proceeded with some aspects of the proposed project in the meantime.

By the time the Combustion Engineering proposal was selected for negotiations in 1988, EPRI had completed the initial version of the Coal Quality Impact Model (CQIM™) and initiated some pilot-scale and commercial power plant testing programs. The result of these efforts and the previous work done by EPRI at the CQDC (and CCTF) were contributed by EPRI to the CQE project and the scope of the project was redefined to incorporate the testing and software development work necessary to complete a rigorous and robust model.

During the course of the project from May 1990 through mid-1996, computer technology and the methodology available to measure and predict coal quality continued to advance, so CQE was developed to incorporate as many of these advancements as possible and to maintain the flexibility to incorporate new features or update existing methodologies economically in the future.

Project Organization

As EPRI's contractor with responsibility for bench-scale and pilot-scale testing to correlate coal quality characteristics to power plant performance, Combustion

Engineering (now ABB CE) submitted the proposal for the CQE project to DOE. While the DOE CCT1 project award decisions were being made, EPRI engaged Black & Veatch to develop the original Coal Quality Impact Model software and Electric Power Technologies to conduct full-scale power plant coal quality impact tests. In addition, coal cleanability characterization efforts continued at the CQDC and EPRI developed plans to establish the CQDC as EPRI's wholly-owned subsidiary.

When DOE selected the CQE project for negotiation, EPRI and Combustion Engineering felt that it was appropriate for CQ Inc., EPRI's subsidiary, to integrate and manage the efforts of the project team as shown on the project organization chart, Figure 1-1.

Under this organization, both CQ Inc. and Combustion Engineering executed the Cooperative Agreement with DOE and both contractors became co-prime contractors for the project with project management and administrative duties being delegated to CQ Inc. Consequently, the project was organized so that each participating organization other than EPRI and DOE would be subcontractors to CQ Inc.

As new computer technologies developed during the project and as the definition of CQE became more defined, some logical changes were made in the project organization. All software coding responsibilities were centralized at Black & Veatch. When a decision was made to exclude the Fireside Troubleshooting Guideline from the CQE code, Karta Technologies' role on the project ended, and when CQ Inc. required assistance with the design of the coal cleaning and blending models, Decision Focus was added to the project team as another subcontractor. The roles of the University of North Dakota Energy and Environmental Research Center (UNDEERC) and PSI Technology were also expanded to include the delivery of fouling and slagging prediction methodology to Black & Veatch.

In recognition of the value of CQE to their customers and to continue their support of EPRI's and DOE's coal quality R&D programs, ABB CE willingly reduced its scope and budget on the project to provide funding for more robust slagging and fouling models for CQE. ABB CE led the efforts with UNDEERC and PSI Technology that distinguish CQE from other software tools that rely on empirical indices to indicate potential slagging and fouling problems.

In addition to its role as co-sponsor, EPRI also provided technical leadership to the project for the pilot-scale and full-scale power plant testing programs and directly managed the software development tasks. EPRI's CQIM User's Group provided a sounding board for CQE development ideas and served as a project advisory committee. Moreover, five members of the user's group served as beta test users of the prototype software.

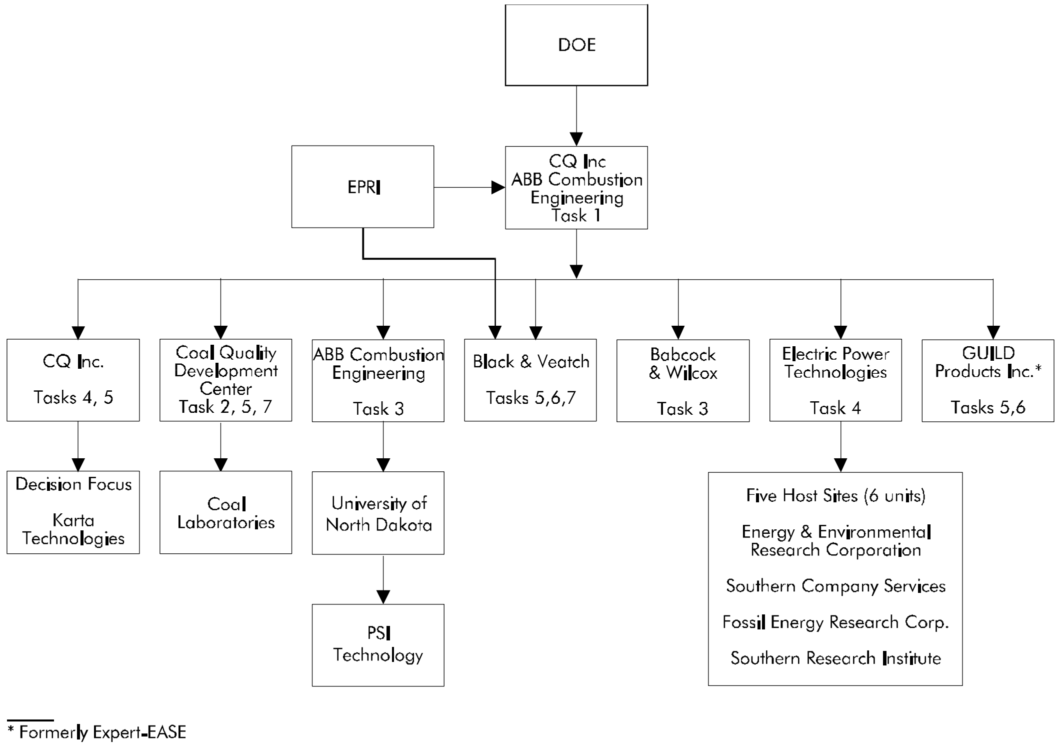


Figure 1-1
Project Organization Chart

Project Description

Although the project mission was to deliver a software tool, the scope of the project included numerous supporting tasks to collect and analyze data to form the basis for CQE algorithms, methodologies and submodels and to verify the accuracy and integrity of the CQE software at the conclusion of the project. These responsibilities are described in Table 1-1.

At the conclusion of each testing program, the responsible contractor prepared a detailed report and data summary for the host utility to use in addressing near-term problems and objectives and to aid the other CQE project contractors in completing their assigned tasks.

Table 1-1
CQE Organizational Responsibility Assignment

Test Sites	ABB/CE and PSIT	B&W	B&V	CQ Inc.	UNDEERC	EPT	GUILD
Northeastern	5 DTFS 5 FPTF	NA	need FT/PT/BT data	2 CCC	4 DTFS 5 SEM	3 FT	NA
Watson	2 DTFS 2 FPTF	NA	need FT/PT/BT data	2 CCC	2 DTFS 2 SEM	2 FT	NA
King	NA	2 SBS	need FT/PT/BT data	5 CCC	2 SEM	2 FT	NA
Gaston	1 DTFS 1 FPTF	NA	need FT/PT/BT data	2 CCC	NA	2 FT	NA
Brayton Point	NA	NA	need FT data	NA	NA	2 FT	NA
Brayton Point	NA	NA	need FT data	NA	NA	2 FT	NA
Other CQE Work	commercial applications and slagging models	NA	CQE software developer, CQIM enhancements, ARA	Coal Cleaning Cost Model, CQIS enhancements, select CQE test sites	ash deposition data & fouling models	Fireside Testing Guidelines	develop CQE shell specs

CCC--Coal Cleanability Characterization
SBS--Small Boiler Simulator (Pilot Test)
BT--Bench Test
DTFS--Drop Tube Furnace System
FT--Field Test
PT--Pilot Test
FPTF--Fireside Performance Test Facility (Pilot Test)
SEM--Scanning Electron Microscopy

The highlights of the project are shown in Table 1-2.

The following U.S. electric utilities cofunded the project and participated in the field testing and software development/testing efforts.

Alabama Power Company
Wilsonville, AL

Duquesne Light Company
Pittsburgh, PA

Mississippi Power Company
Gulfport, MS

New England Power Company
Somerset, MA

Northern States Power
Oak Park, MN

Public Service Company of Oklahoma
Oologah, OK

Southern Company Services
Birmingham, AL

Table 1-2
Project Accomplishments

Accomplishment	Date
DOE awarded Cooperative Agreement	5/3/90
First of six field tests started	7/90
Pilot and bench-scale testing started	11/90
CQE specifications completed	2/15/92
Pilot and bench-scale testing completed	6/92
Acid Rain Advisor--first commercial product--released and copy sold	3/93
Completion of all six field tests	4/93
CQ Inc. and B&V signed CQE commercialization agreements	10/13/93
Conceptual design of the general Interactive Output Utility completed	8/94
Partially functional CQE beta version successfully tested	12/94
CQE alpha-version completed	3/31/95
CQE beta version completed and released for testing	6/95
Beta testing complete	11/30/95
CQE revised and issued on CD ROM	12/95
CQE Release 1.1 beta issued	6/7/96
Final Report	8/96
CQE Release 1.0	12/96

CQE builds on existing correlations from worldwide R&D on the impacts of coal quality for specific parts of the total power generation system. CQE features EPRI's CQIM as the calculational foundation for determining the impacts of different coals on plant performance and costs, and EPRI's Coal Quality Information System (CQIS™) provides a national database of coal quality information.

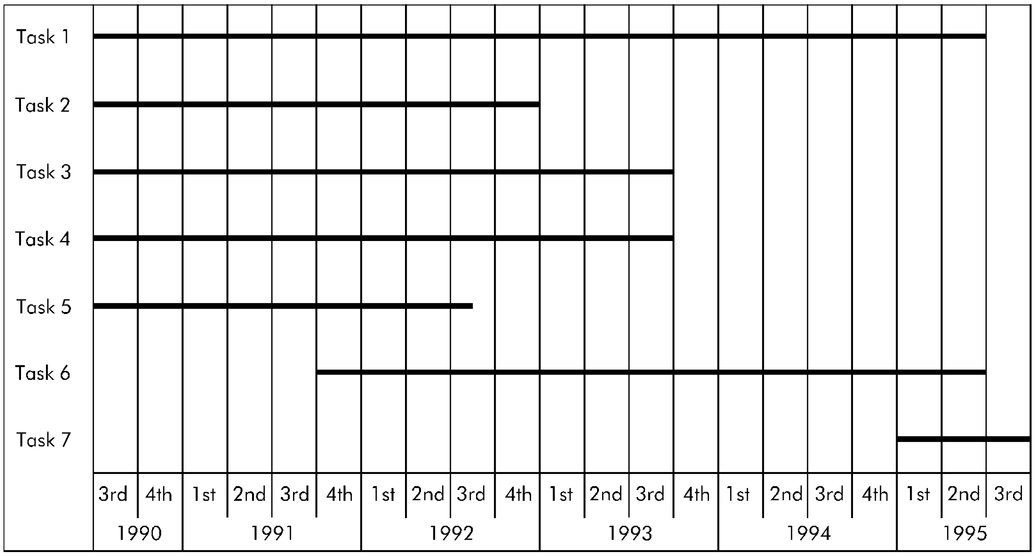
CQE combines the expertise from these established models--or the models themselves--into a single, personal computer-based tool. The electronic consultations that occur transparently between CQE's models let users address all aspects of fuel issues and their corresponding impacts on power generation systems.

This groundwork of established models is complemented by new and enhanced models derived from bench-, pilot-, and full scale test programs. These test programs, which allow coal-related effects to be distinguished from operational or design impacts, are among the most extensive of their kind ever conducted to relate power plant performance and emissions to coal quality.

Project Schedule

The original 42-month project actually spanned 64 months because the required "off-the-shelf" software for OS/2 was late.

The extended duration of the project required increased funding from EPRI and DOE, but it ensured that CQE was adequately planned and that CQE's underlying computer software was adequately proven. The project schedule is given in
Figure 1-2.



Task 1 - Project Management
Task 2 - Coal Cleanability Characterization
Task 3 - Pilot-Scale Combustion Testing
Task 4 - Utility Boiler Field Testing
Task 5 - CQIM Completion & Development of CQE Specifications
Task 6 - CQE Development
Task 7 - CQE Workstation Testing and Validation

Figure 1-2
Project Schedule

Objectives of the Project

The work falls under DOE's Clean Coal Technology Program category of "Advanced Coal Cleaning." The 64-month project provides the utility industry with a PC software program to confidently and inexpensively evaluate the potential for coal cleaning, blending, and switching options to reduce emissions while producing the lowest cost electricity. Specifically, this project was designed to:

- Enhance the existing Coal Quality Information System (CQIS) database and Coal Quality Impact Model (CQIM) to allow confident assessment of the effects of cleaning on specific boiler cost and performance.

- Develop and validate a methodology, Coal Quality Expert (CQE), which allows accurate and detailed predictions of coal quality impacts on total power plant operating cost and performance.

Significance of the Project

Originally, coal cleaning technologies were used only to remove ash-forming mineral matter. After passage of the 1970 Clean Air Act, coal cleaning processes were applied to a second purpose--sulfur reduction--accomplished primarily by removing the sulfur-bearing mineral pyrite. A great deal of geochemical information concerning the modes of occurrence of pyrite in coal was gathered and used to develop new methods of sulfur removal and to enhance existing methods. Today, coal cleaning plays a larger role in controlling SO_2 emissions than all post combustion control systems combined. It has led to reduced SO_2 emissions while U.S. coal use by utilities has increased steadily since 1970 (see Figures 1-3 and 1-4).

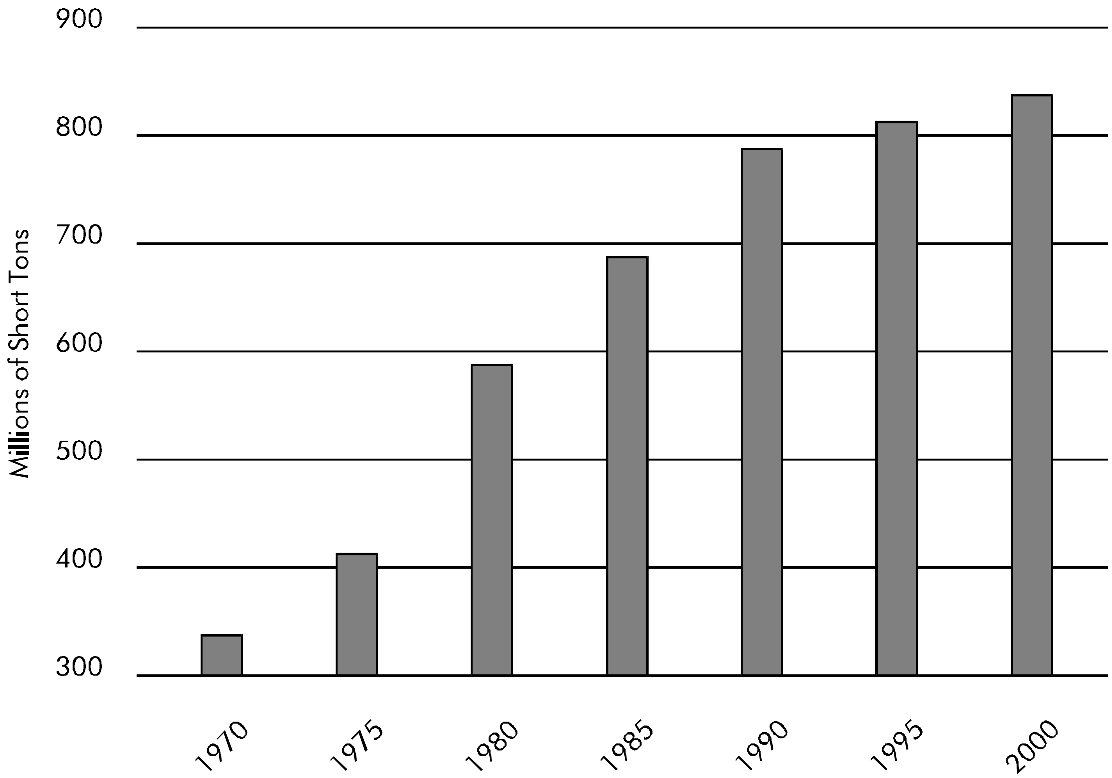


Figure 1-3
U.S. Utility Coal Use

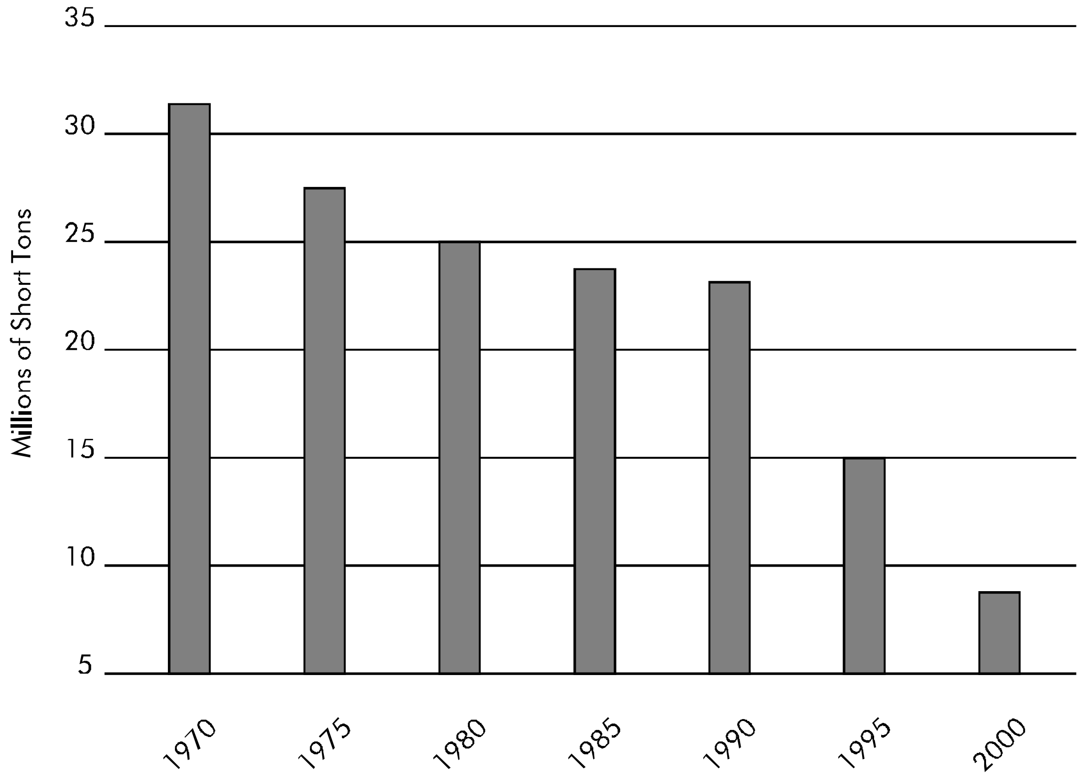


Figure 1-4
Total U.S. SO_2 Emissions

Coal cleaning has been commercially demonstrated as a means of reducing sulfur concentrations in some types of coal to levels which allow firing in boilers to conform to environmental standards without using scrubbers. In addition, coal cleaning reduces the concentrations of mineral impurities which may result in significant improvements in boiler performance, reduced maintenance, and increased availability. Figures 1-5 and 1-6 illustrate trade-offs which dictate the feasibility of coal cleaning. Sulfur emissions produced when burning a coal generally decrease with increased levels of cleaning. Fuel costs, however, increase with increased levels of cleaning (Figure 1-5). Another consideration is that performance benefits can increase with increased cleaning for existing units and higher quality fuel reduces new unit capital costs (Figure 1-6).

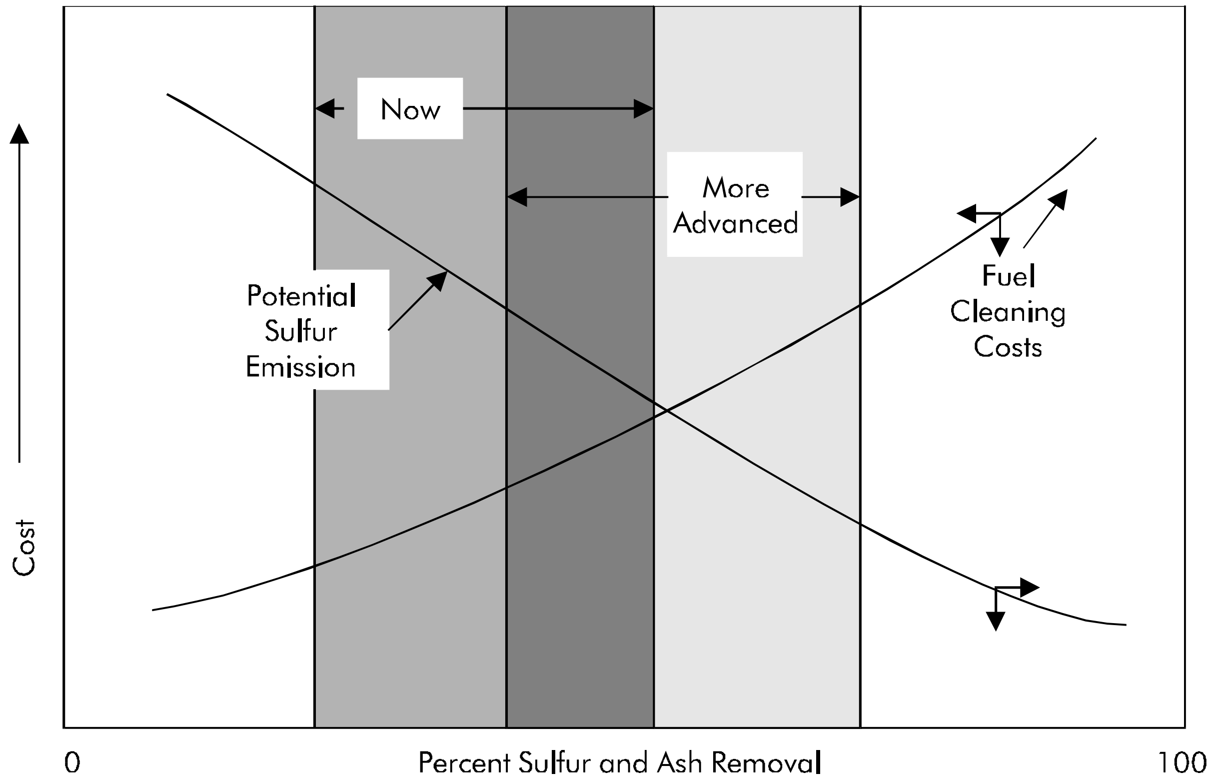


Figure 1-5
The Relationship Between Sulfur Emissions and Fuel Costs

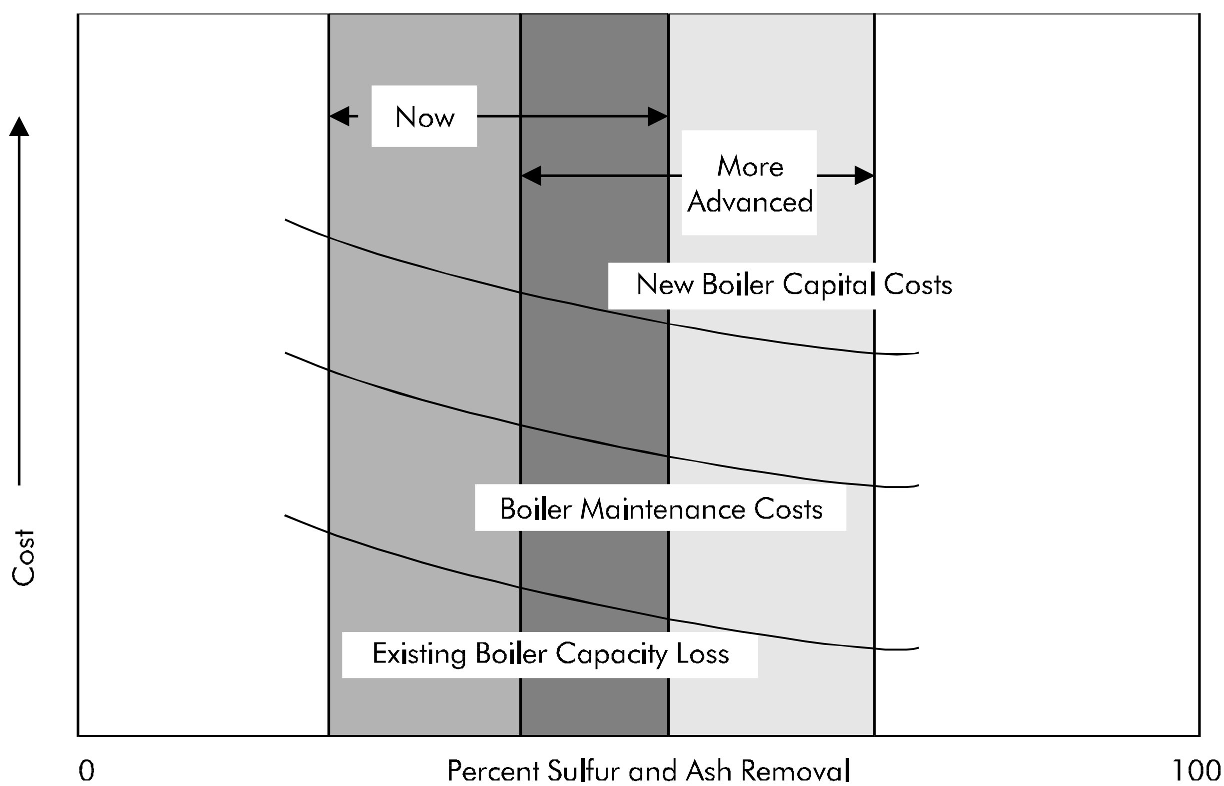


Figure 1-6

Coal Cleaning to Reduce Power Production Cost

Studies have indicated significant economic benefits due to coal cleaning (2). However, to accurately and completely assess the commercial viability of cleaning a particular coal, detailed large-scale combustion testing is necessary. Quantification of performance savings is necessary to compare the economic benefits obtainable through coal cleaning with the costs of other techniques for emission control. Industry currently does not have the capability to reliably predict the performance of cleaned coals without extensive studies. The relationship between level of confidence and testing coals is illustrated in Figure 1-7. Since many of today's bench-scale coal performance indices rely on empirical correlations, extrapolation of these indices to fuels not represented by the specific database used for correlation can be misleading. The need for quick, inexpensive tests that can be reliably used to assess the commercial impacts of coal cleaning is vital to implement clean coal technology. One of the major goals of the program was to develop and demonstrate simple techniques (bench-scale fuel properties and predictive models) to allow industry to confidently assess the overall impacts of coal quality and the economic implications during utilization.

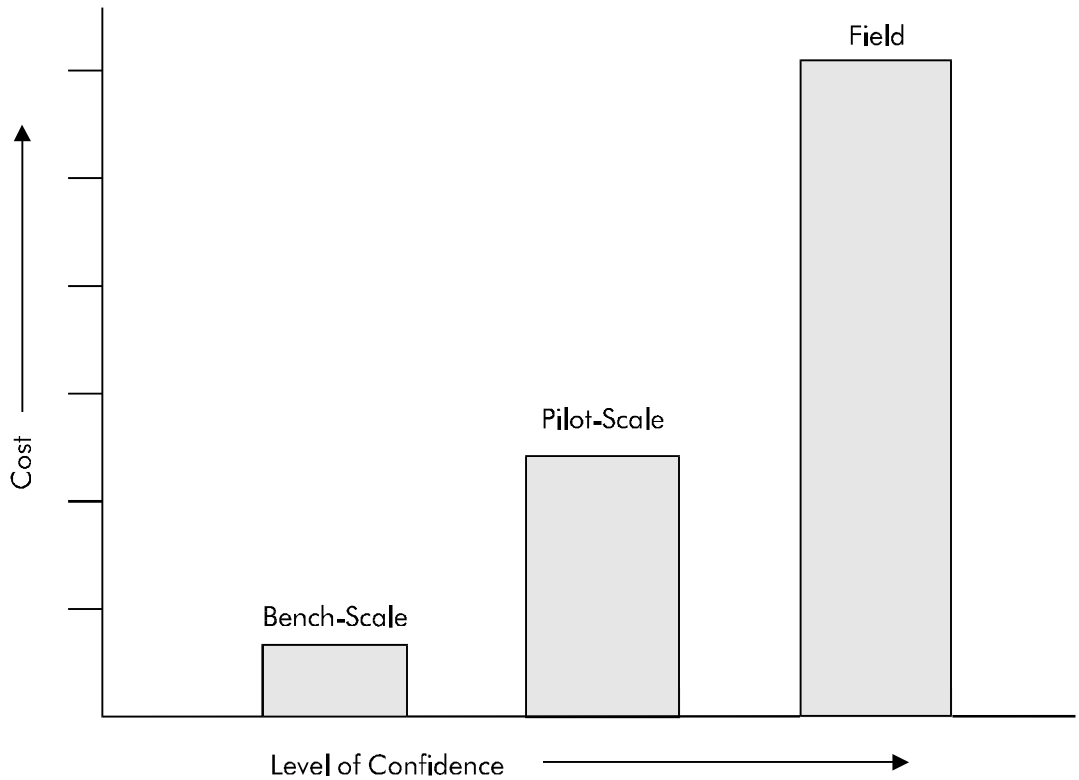


Figure 1-7
Relationship Between Testing Cost and Confidence Level of Commercial Predictions

The Significance of the CQE Tool

Fuel decisions affect nearly every aspect of power generation. Fuel buyers handle transportation issues and coal sourcing; plant engineers evaluate how individual coals behave in a unit; and environmental engineers address compliance and disposal issues. Typically, each expert uses an individual set of assumptions, data, and tools to complete an evaluation, resulting in one-dimensional pictures of fuel-related costs.

CQE integrates these assumptions, data, and tools, creating a unique electronic forum within which experts can efficiently and effectively share their knowledge and results.

The power of the forum is twofold. It not only centralizes all relevant information, it makes that information available to all other experts as appropriate. The end result of integrating a set of previously isolated analyses is a new capability that provides a complete picture of fuel-related impacts and costs.

One new capability, for instance, is CQE's ability to evaluate the economic tradeoffs between coal cleaning and scrubbing (Figure 1-8). Traditionally, utility engineers would combine results from two different models to compare the costs of cleaning and scrubbing. In contrast, a CQE analysis of cleaning versus scrubbing captures and consolidates the results of required analyses to determine the most cost-effective option or combination of options.

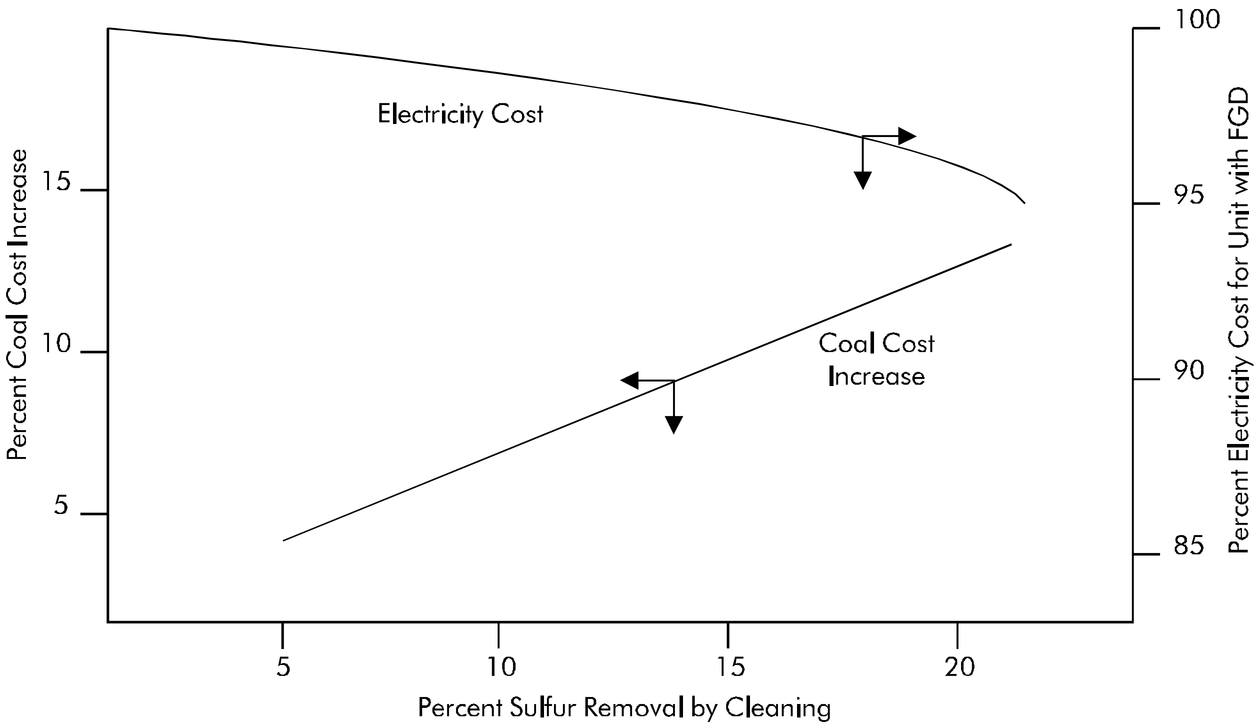


Figure 1-8
Economic Impact of Coal Cleaning

Commercial Potential and Plans

An analysis of the market for CQE shows that the most likely customers for CQE are power generation organizations, fuel suppliers, environmental organizations, government organizations, and engineering firms. These world-wide organizations can take advantage of CQE's ability to evaluate the impact of fuel quality on entire generating systems.

EPRI owns the software and distributes CQE to EPRI members for their use, and has contracted CQ Inc. as their commercialization agent. CQE is available to others in the form of three types of licenses: use, consultant, and commercialization. The largest market for use licenses with an introductory price of $90,000 is power generation organizations. Coal producers and equipment manufacturers are also prospective users. Large architect/engineering firms and boiler manufacturers are most likely to purchase consultant licenses or regional or world-wide commercialization licenses.

Black & Veatch executed the first CQE commercialization license with CQ Inc (as agent) and CQ Inc. is also licensed to commercialize CQE. Under the terms of that license, B&V and CQ Inc. are working collaboratively to sell use and consultant's licenses worldwide to provide consultation to organizations with coal quality projects and to continue the development of CQE software enhancements. Copies of CQE's stand-alone Acid Rain Advisor have been licensed to two U.S. users to date.

Conclusions and Recommendations

CQE will benefit owners and operators of coal-fired power plants in their commitments to produce energy economically and with concern for the environment. Utilities now have a tool to evaluate the system-wide consequences of fuel purchase decisions on power plant performance, emissions, and power generation costs. The software can examine potential changes in coal quality, transportation options, pulverizer performance, boiler slagging and fouling, emissions control alternatives and byproduct disposal for pulverized-coal and cyclone-fired power plants.

CQE will warrant further refinement and updating as new predictive models are validated. Future development of CQE should include coal gasification, fluidized bed boilers, European and Asian boiler design, and post combustion SO_2 and NO_x control technologies that are successfully demonstrated in U.S. Clean Coal Technology projects.

References

1. *Coal Preparation for Combustion and Conversion*, EPRI AF-791, Project 466-1 Final Report, May 1978, Gibbs & Hill Inc., NV.

2. *Impact of Coal Cleaning on the Cost of New Coal-fired Power Generation*, EPRI CS-1622, Project 1180-2 Final Report, May 1981, Bechtel National Inc., San Francisco, CA.